Labrador Sea Boundary Current and Convection Dynamics

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LONG-TERM GOALS

Our aim in this terminal year of our ONR support has been to understand the physics of high-latitude convection, eddies and circulation, using direct observations made as part of the ONR Deep Convection ARI, and subsequently in collaborative surveys with Canadian oceanographers. Of growing importance is the dynamics of fresh water: cycled through the atmosphere and terrestrial cryosphere, falling as precipitation, and recycling through sea-ice.

OBJECTIVES

The specific questions under study have been: what is the source of the mesoscale eddies which populate the Labrador Sea? What determines the sign and size of these eddies? Why did the weakening of cold-winter forcing of the Sea cause the dominant eddy energy to rise, and the eddies to be warm-core rather than cold-core? How does the annual cycle of heat storage and fresh-water storage in the Labrador Sea compare with the atmospheric forcing inferred from atmospheric centers' (NCEP and ECMWF) data? Is the oceanic water column in fact a better index of atmosphere-ocean heat flux than are the weather models? How does the Sea respond when atmospheric forcing is switched off for several years? Can we describe in detail the interaction of the 500 km wide Labrador Sea Water gyre with its encircling boundary currents; what is the out-mixing rate for Labrador Sea Water, which communicates with the surrounding ocean? Can the dynamics of fresh water at high latitude be understood?

APPROACH

The data sets we have analyzed include 6 years of mooring data, predominantly that of the Bravo mooring supported under NOAA funding, supplemented with ONR support; hydrography from the Hudson section between Hamilton Bank, Labrador and Cape Desolation, Greenland, most years in the 1990s, and special, 3-dimensional hydrographic programs involving the PI and BIO, October 1996 and May 1997. In addition, ONR funded moorings on the Labrador continental slope yielded valuable data about the strong boundary current circulation, which catches the dominant Denmark Strait Overflow water and other water masses that feed the global circulation. Finally, we are funded by ONR in a separate grant to use the Eriksen Seaglider in the subpolar North Atlantic to make dense, interactive, 3-dimensional observations of temperature, salinity, dissolved oxygen, chlorophyll and nitrate with cost efficiency that is orders of magnitude better than currently possible.

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14. ABSTRACT
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WORK COMPLETED

Jonathan Lilly, graduate research assistant under this grant, successfully defended his Ph.D. thesis in May 2001. He has combined Topex-Poseidon and ERS altimetry with our hydrography and mooring data, to describe the annual cycle of eddy energy in the Labrador Sea. Lilly has developed an ‘eddy finder’ that can scan altimeter or current-meter data and isolate identifiable eddies. This is important when dealing with the vast amounts of data collected by remote sensing. This is used to carry out an eddy census, and with it map the eddy kinetic energy.

He has also done a detailed study of restratification of the Sea after winter is over, when the water column relaxes back toward the warm, saline properties of the surrounding ocean. This restratification also continues over longer time-scale, during years when winters are warm and mild. The portrait of the water column from 1990 to 2000 is a striking example of massive interannual variability of convection depth, eddy energy, and circulation. We have scheduled the deployment of Seagliders in the region, and ONR has approved a proposal to develop deep hulls and begin with the first deep-sea, satellite tracked deployments anywhere in the world ocean. Private foundation support will be used for the first deep-ocean deployments.

RESULTS

The origin of mesoscale eddies in the Labrador Sea has not before been established. Many numerical model studies have looked at their production by convective cooling, and that has been the working hypothesis (e.g., Jones and Marshall, 1994). We know from lab and numerical models that wintertime cooling of a patch of ocean will quickly generate 100m to 500m wide plumes and, at the ‘edges’ of the cold forcing region, 10 km to 100 km mesoscale eddies. However Lilly has shown under this grant that boundary current instabilities are also very active in the Labrador Sea, and supply a significant amount of the observed eddy field in the central Labrador Sea. The boundary currents flow counterclockwise round the Sea, separating from Greenland and flowing in deep water southwest to the Labrador continental shelf. At the separation point from Greenland, direct AVHRR temperature images and altimetry both show intense eddy activity. SAR images also show dipole eddy pairs shooting off the Labrador boundary current at Hamilton Bank. Lilly’s work with Topex-Poseidon satellite altimetry (Fig. 1) emphasizes this source. In a careful analysis of the time-dependence of the eddy energy, and of tracks of individual eddies, he follows the progress of the eddy field as it crosses from the Greenland slope to the ocean interior.

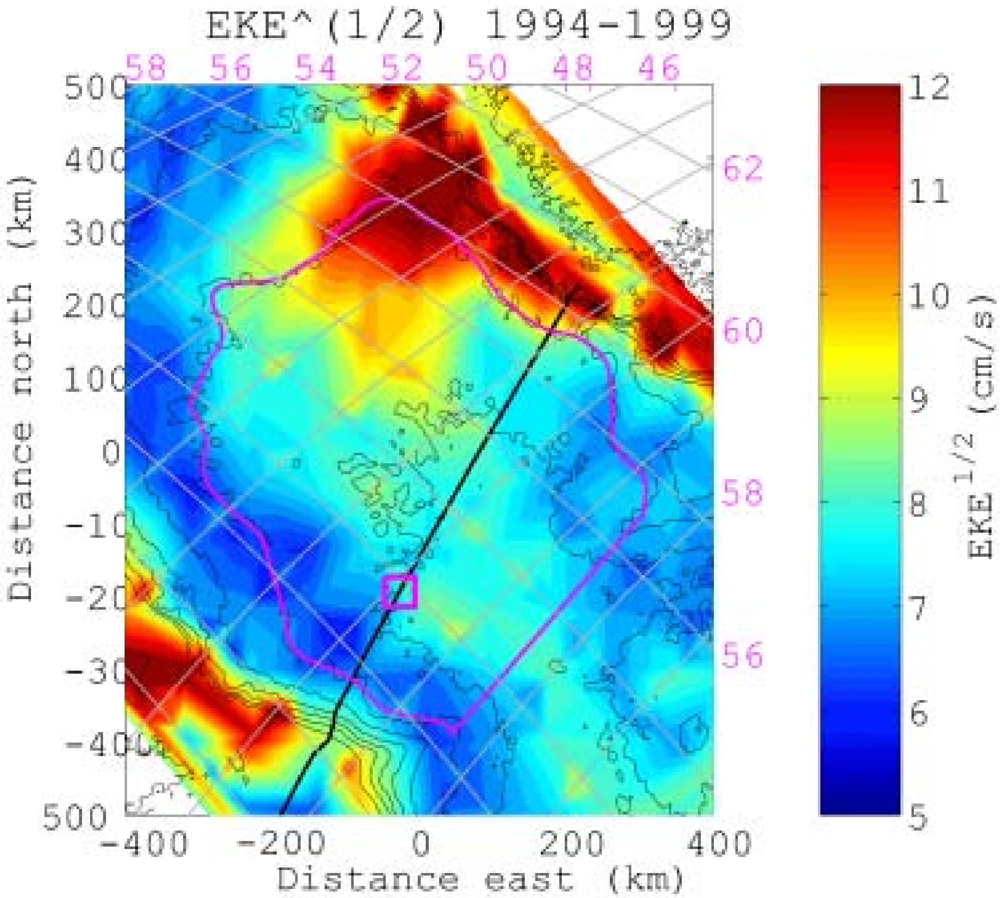

Fig. 1. The square-root of the eddy kinetic energy in the Labrador Sea, averaged from 1994 to 1999. The Bravo site is the small square. Strong eddy energy occurs in the anticyclonic boundary currents, and especially where the Greenland boundary current separates from the coast. The eddy energy floods across the Sea.

Our long-term site mooring at station Bravo in the central Labrador Sea has provided a climatology of eddy activity between 1994 and 2000 (Fig. 2). With NOAA and ONR support terminated, this site will no longer be instrumented by US oceanographers. This time period has seen large swings in climate, with both the strongest and weakest cold wintertime forcing of the century. The ocean feels these changes. Surprisingly, the eddy field has reacted by becoming shallow (baroclinic) and intense during *weak* forcing and deep (barotropic) and less intense during strong atmospheric forcing.

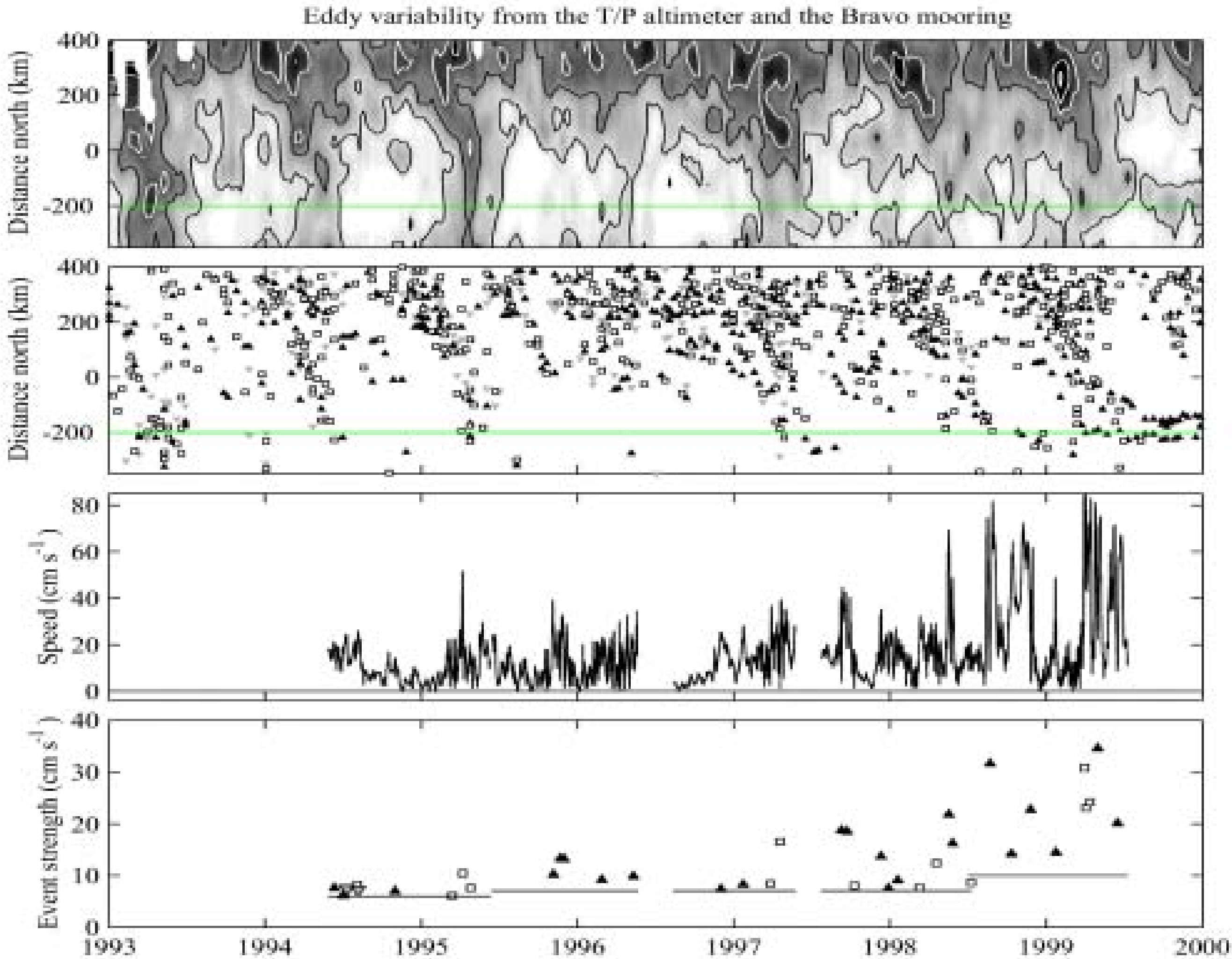

Fig. 2. Interannual change in eddy energy seen at the Bravo mooring site, 1993-2000. Top panel: satellite altimeter signal for entire Labrador Sea on ascending track close to Bravo. Second panel: Individual eddies vs. distance and time, showing southeastward movement from Greenland slope. Third panel: speed at 1000m at Bravo mooring showing annual cycle of strongly forced winters, giving way to much stronger eddies during mild, weakly forced winters. Fourth panel: strength of extreme eddy events (symbols) plotted over rms annual average strength.

The mooring record of speed at various depths can be compared with the satellite overflights (Fig. 4). The Topex-Poseidon altimeter does not reliably see eddies of diameter less than about 25 km. Hence in this comparison we see strong sea-surface height signals for only the larger-diameter eddies. The vertical structure of the eddies is also not evident from altimeter data. From the Bravo mooring we see (fig. 2) that the recent mild winters are dominated by shallow, very intense baroclinic eddies originating in the boundary current, and often containing warm Irminger Current water. During cold winters, as in the first year of the Bravo mooring documented by Lilly *et al.* (1999), the eddies often encapsulated cold, recently convected water.

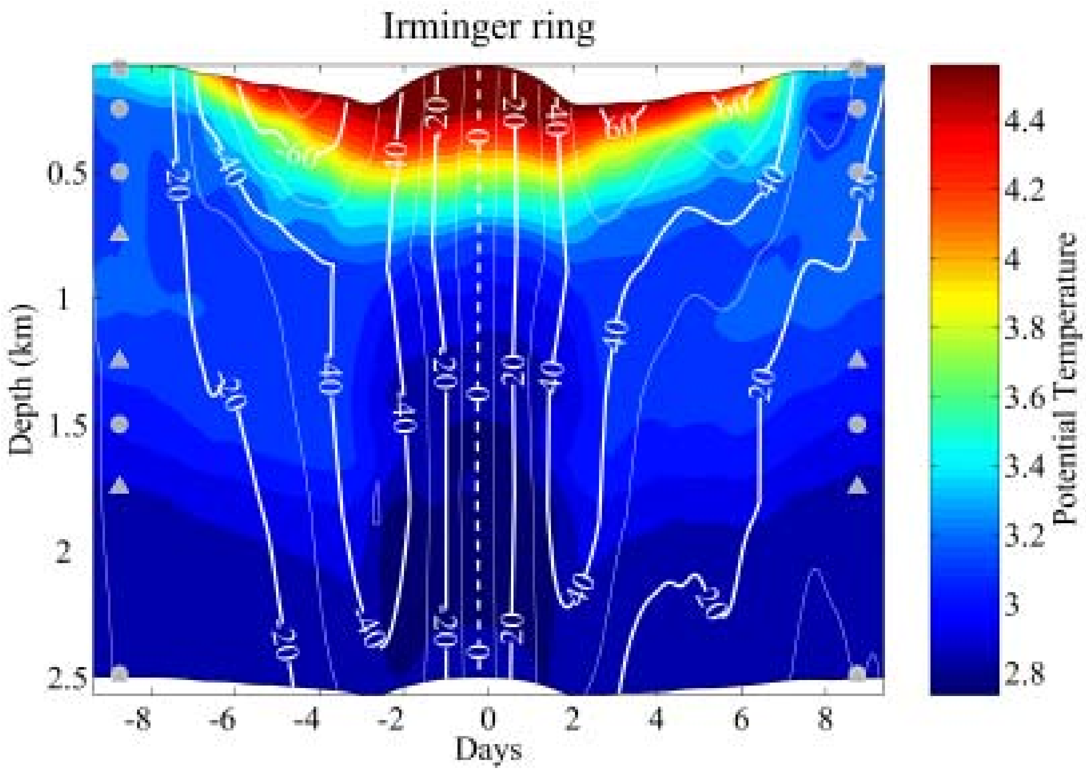

Fig. 3. Cross-section from the Bravo mooring site of an 'Irminger ring' of the kind dominating the central Labrador Sea in weakly convecting years. Velocity contoured over temperature colors shows the deep penetration of the velocity of the eddy, compared with its warm temperature anomaly. The horizontal scale is time, but using the eddy detection algorithms it can be related to horizontal distance; the eddy is about 60 km in diameter.

IMPACT/APPLICATIONS

Numerical models of the ocean are vulnerable to poorly resolved and understood physics in the subpolar and Arctic regions. Only with an articulate set of observations will this situation improve. The problem of data assimilation and modeling is particularly severe in the upper ocean, where very buoyant, fresh melt waters interact with strong wind mixing and circulation. Density and sound-speed profiles are chaotic.

We also have continued a many-year effort in education and public outreach. See:
(http://www.ocean.washington.edu/research/gfd/gfd/html).
(http://www.ocean.washington.edu/courses/oc512/gfd1.html).

RELATED PROJECTS

1 – We (C.Eriksen and the PI) are fundec by ONR the deployment Seagliders in the Labrador Sea in 2003.

2 – Jerome Cuny and the PI have analyze sea-surface drifters (Niiler program) in the Labrador Sea. Cuny, being a non-US citizen, is funded by NSF. There is much interaction with the current ONR work however (Cuny *et al.* 2000).

3 – Leif Thomas, a student under NSF support, and the PI have been investigating the geophysical fluid dynamics (GFD) of stratified spin-up and generation of fronts, when wind and cooling are applied to the surface of a stratified ocean.

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